SHIELDING PROPERTIES OF NEW GRADES OF PRECIPITATION

HARDENING STAINLESS STEEL

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ABSTRACT

The specific objective of this work is to compare the neutron shielding properties of innovative Maraging steel containing chromium and titanium with the conventional Maraging steel C250. For all steel under investigation, neutron shielding properties were measured using MCNP5 program.

The results show that, the total macroscopic cross-section, Σ_t increase with the increase of Cr content in the tested steel which increase the ability of steel in neutron attenuation. In addition, the new grades of cobalt free, low nickel, containing chromium Maraging steel is promising material as a neutron shielding material compared with the generally used Maraging steel C250.

KEYWORDS: MCNP5 Program, Neutron Shielding, Maraging Steel

INTRODUCTION

Practically, neutrons and gamma rays are the important concern in shield design. Therefore, attenuation of neutrons and gamma rays should be involved in shielding analysis. Also, the associated gamma rays produced due to neutron inelastic scattering, neutron thermalization and thermal neutron capture should be studied. In addition, the neutron energy loss and there following through the shielding materials (deposited energy) may have thermal and radiation damage effects which should be analyzed.

Maraging steels are low carbon martensitic steels that can be hardened by precipitation of intermetallic phases. These steels are used in industrial applications that demand high strength steels, such as in aerospace and nuclear technologies [1]. Commercial Maraging steels are iron-nickel-cobalt alloys with molybdenum, titanium and aluminum additions. Great efforts were done by many investigators to innovate cobalt free low-nickel Maraging steels to replace the costly conventional cobalt high-nickel Maraging steels. Cobalt, molybdenum with nickel have great effect on strengthen of the produced Maraging steel. However, reduce nickel content and eliminate the cobalt leads to decrease the designed strength of the produced steel. Reducing the nickel content to 12 mass % in cobalt free Maraging steels inhibits the transformation of martensite to austenite and overcomes the problem of its over-aging beside it reduces its cost. In innovation trial to produce such kind of steel, reduce the nickel content accompanying with the addition of chromium and titanium increase the designed strength and overcome the problem of over-aging which in turn reduces the cost of produced steel. On the other hand, there are leakages in published data on shielding properties of new grades of cobalt free low nickel Maraging steel. The shielding properties of materials under investigation were performed by MCNP5 program

[2]. MCNP5 is a general-purpose Monte Carlo N-Particle code that can be used in several transport modes: neutron only, photon only, electron only, combined neutron/photon transport where the photons are produced by neutron interactions, neutron/photon/electron, photon/electron, or electron/photon. The user creates an input file that is subsequently read by MCNP5. This file contains information about the geometry, the type of materials and the selection of a specific cross-section library. The input file includes the location and characteristics of the neutron, photon, or electron sources, the type of answers or tallies desired, and any variance reduction techniques used to improve efficiency.

In this work, the shielding properties of experimental chromium and titanium containing Maraging steel were studied and compared with the result of the standard Maraging steel C250 (cobalt containing Maraging steel, 18% Ni) under the same experimental conditions.

EXPERIMENTAL WORK

Total Macroscopic Cross Section of Neutrons, Σ_t.

The total macroscopic cross section of neutrons, denoted by Σ_t is the factor which determines the ability of a material to attenuate the neutrons passing through it. This physical quantity (Σ_t) depends on two parameters, the number of atoms per unit volume present in the traversed material (N) and the total microscopic cross-section of each atom (σ_t). It is worth to mention that, the total microscopic cross-section of an atom is the summation of its scattering microscopic cross-section (σ_s) and absorption microscopic cross-section (σ_a). I.e. σ_t can be defined by,

$$\sigma_t = \sigma_s + \sigma_a \tag{1}$$

Therefore, the total macroscopic cross-section Σ_t can be defined by

$$\Sigma_t = N\, \sigma_t \tag{2}$$

The value of Σ_t can be estimated from the following Beer Lambert law [3-8], which determine the variation of neutron intensity vs. thickness of the absorber material.

$$I_x = I_0\, e^{-\Sigma_t\, x} \tag{3}$$

where I_0 is the initial neutron intensity (with material thickness x=0), I_x refers to those neutrons that penetrate a distance x in the material.

Σ_t Calculations

MCNP5 program was used to simulate our experiment setup. The source of neutrons was simulated as a 14.1 MeV monoenergitic isotropic source, placed inside a lead box with a collimator opining of 4 cm diameter. The investigated steel materials with different thicknesses (5, 10, 15 and 20 cm) were placed in front of the aperture of the collimator followed by the detector which surrounded by a lead shield as shown in **Fig**ure **1**. [9]. The elemental compositions of steels under investigation are shown in **table 1**. Tally type 4 was used in our calculations to estimate neutrons registered in the detector per MeV. cm^2. s^{-1}. The number of particle histories used in the input file of the program was 15×10^7. The statistical uncertainty with this number of particle histories did not exceed 10% in all energy bins (1 keV energy bin).
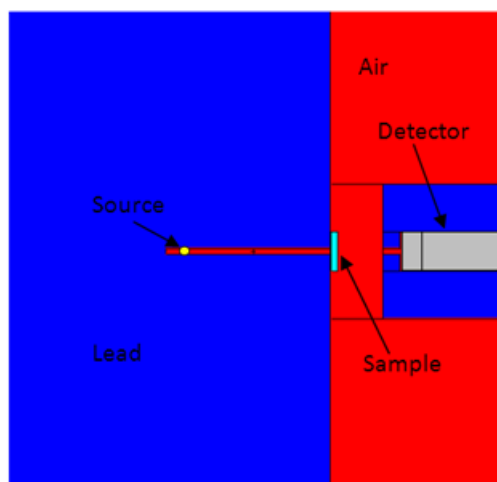
**Figure 1: MCNP5 Vertical Cutoff View (YZ Cross-Section) for Neutron
Attenuation Experiment Setup (Dimensions Are Not to Scale)**

Table 1: Chemical Composition of the Investigated Steels

Chemical Composition							
Steel No	C	Ni	Mo	Co	Cr	Ti	Fe
M3	0.017	11.7	0.01	-	0.05	0.71	87.45
M4	0.066	11.6	4.8		0.26	0.59	82.61
M5	0.049	12.5	4.5		5.4	0.63	76.83
M6	0.031	13.5	4.2		11.5	0.13	70.54
C250	0.010	18	4	12		1.6	64.40

RESULTS AND DISCUSSIONS

The measured values of I_0 and I_x are the required to draw a diagram for $ln\frac{I_0}{I_x}$ vs. x. The slope of the straight line obtained is the total macroscopic cross-section for the used steel (see equation 3). **Table 2** shows the values of Σ_t and the atom density ρ for all steels used in our present work. As shown in **table 2**, the value of Σ_t increase with the increase in Cr content in the tested steels. This means that, the Cr element concentration affects the ability of steel in neutron attenuation. The effect of increase Cr content in neutron attenuation also increases with material thickness increase for the investigated steels as shown in **Fig**ure **2**. The figure shows the total neutron integral flux accumulated in the detector for the different investigated steels at different thicknesses. The integral flux decrease with increasing the material thickness and also have a deeply decrease with the Cr content increase.

**Table 2. Total Macroscopic Cross-Section Σ_t (Cm^{-1}) and Atom Density
P (10^{24} Atoms/Cm^3) for the Investigated Steels**

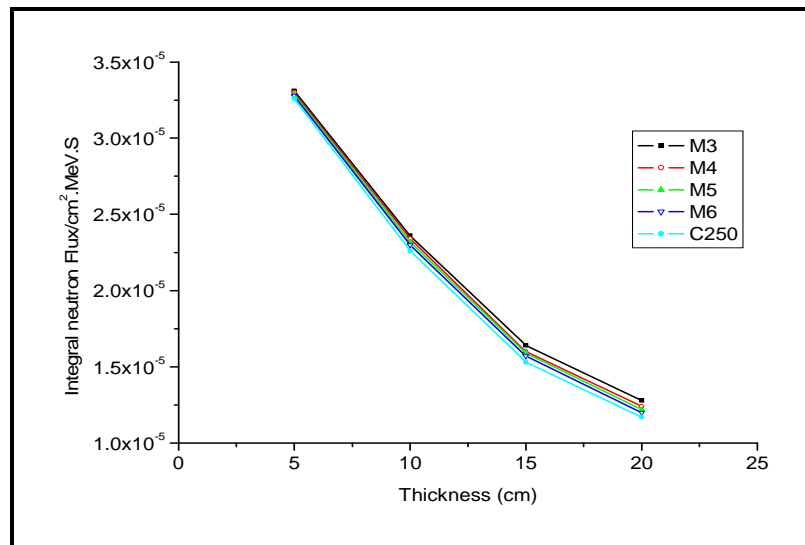| Steel No.	Total Macroscopic Cross-Section Σ_t (cm^{-1})	Atom Density ρ (10^{24} atoms/cm^3)
M3	0.0642	8.43458E-02
M4	0.0664	8.15856 E-02
M5	0.0669	8.19927 E-02
M6	0.0678	8.23911 E-02
C250	0.0694	8.13271E-02

Figure 2: The Integral Neutron Flux Vs. the Material Thickness for All Investigated Steels

Interaction of neutrons with shielding materials is known to affect them in their chemical structure. The energy deposited through the shielding materials due to radiation interactions rises its temperature. This temperature depends on not only the energy of radiation, but also the fluency of radiation.

MCNP5 program calculates the deposited energy through the shielding materials under investigation. **Figure** 3 shows the energy deposited through the investigated steels with thicknesses 5, 10, 15 and 20 cm. In addition **Figure 3** shows that, the material with large value of total macroscopic cross-section have a large value of deposit energy. Also, the **figure** shows a large value of energy deposited through steel material M3 that have a higher atomic density than the other materials. The number of neutron interactions in the higher atom density material increase without effect on neutron attenuation due to the high neutron energy.
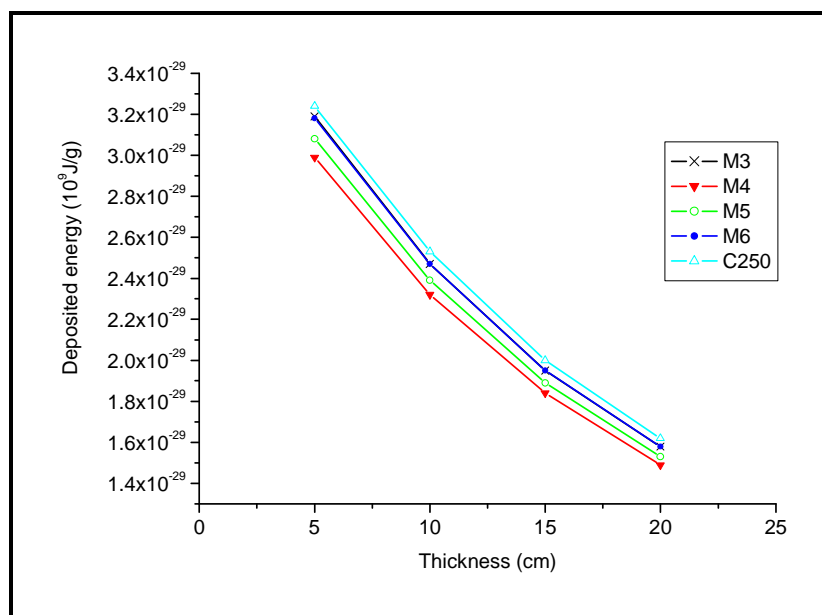

Figure 3: The Energy (10^9 J/G) Deposited through Different Thicknesses for the Different Investigated Steels

Secondary gamma-rays produced due to the different ways of neutron interaction with the material was estimated and illustrated in **Fig**ure **4**. For all the investigated steels there is no obvious difference in the integral gamma-ray flux. Also, the integral flux of gamma-rays decrease with the material thickness increase due to the self shielding of the material.
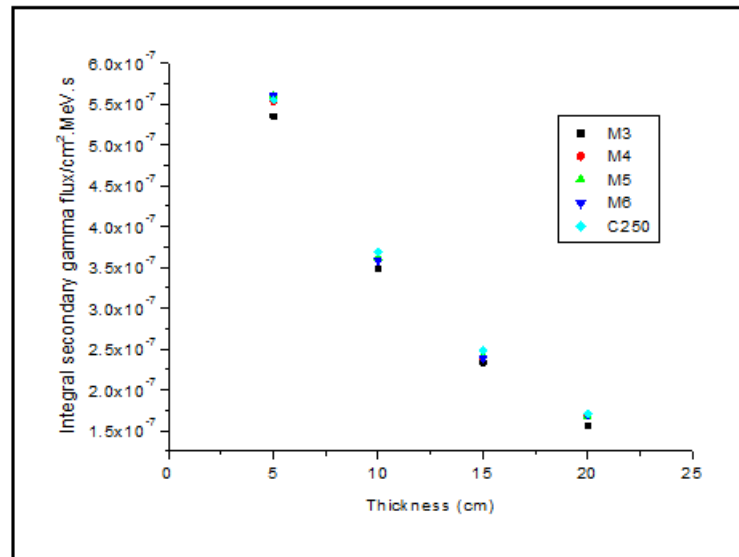

Figure 4: The Integral Secondary Gamma-Ray Flux Vs the Material Thickness for All Investigated Steels

CONCLUSIONS

It was found that the value of total macroscopic cross-section Σt increase with the increase in Cr content in the tested steels. This means that, the Cr element concentration affects the ability of steel in neutron attenuation. In addition a large value of energy deposited through steel material M3 that have a higher atomic density than the other materials make it candidate to be used in the shielding application that needs a heat hold materials. Therefore, from the economic point of view, cobalt free, low-nickel, chromium contain Mraging steel is promising material as neutron shielding material incomparable with the result of standard Maraging steel C250 (cobalt containing Maraging steel, 18% Ni).

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